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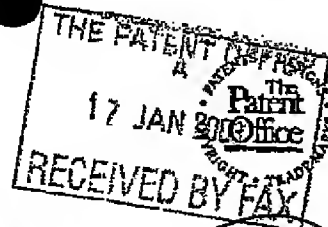
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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

17 JAN 2003

The Patent Office

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1. Your reference

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2. Patent application number

(The Patent Office will fill in this part)

0301093.1

3. Full name, address and postcode of the or of 1... Limited

each applicant (underline all surnames)

St John's Innovation Centre

Cowley Road

Cambridge CB4 0WS

Patents ADP number (If you know it)

If the applicant is a corporate body, give the country/state of its incorporation

England

8113870001

4. Title of the invention

SET-UP METHOD FOR ARRAY-TYPE SOUND SYSTEMS

5. Name of your agent (If you have one)

Akram K. Mirza

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

1... Limited

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Cambridge CB4 0WS

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Patents ADP number (If you know it)

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (If you know it) the or each application number

Country

Priority application number
(If you know it)

Date of filing
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

YES

- a) any applicant named in part 3 is not an inventor, or
 - b) there is an inventor who is not named as an applicant, or
 - c) any named applicant is a corporate body.
- See note (d))

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SET-UP METHOD FOR ARRAY-TYPE SOUND SYSTEM**FIELD OF THE INVENTION**

5 This invention relates to a device including an array of
electro-acoustic transducers capable of receiving a multi-
channel audio input signal and to produce independently
steerable and focusable beams of audible sound, at a level
suitable for home entertainment or professional sound
10 reproduction applications. More specifically, the invention
relates to the methods and systems for configuring such a
device.

15

BACKGROUND OF THE INVENTION

The commonly-owned International Patent applications no. WO-
0123104 and WO-02078388 describe an array of transducers and
their use to achieve a variety of effects. They describe
methods and apparatus for taking an input signal, replicating
20 it a number of times and modifying each of the replicas before
routing them to respective output transducers such that a
desired sound field is created. This sound field may comprise
a directed, steerable beam, focussed beam or a simulated
origin. The methods and apparatus of the above and other
25 related applications is referred to in the following as "sound
projector" technology.

Conventional surround-sound is generated by placing
loudspeaker at the appropriate position surrounding the
30 listener's position or "sweet-spot". Typically, a surround-
sound system employs a left, centre and right speaker located
in the front halfspace and two rear speakers in the rear
halfspace. The terms "front", "left", "centre", "right" and
"rear" are used relative to the listener's position and
35 orientation.

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correlation is calculated by adding the absolute values of the convolved signal at each repeat of the sequence, to improve the signal-to-noise ratio.

5 The above impulse measurement is performed for several different transducers in the array of the sound projector. Using multiple sufficiently uncorrelated sequences can shorten the time for these measurements. With such sequences it is possible to measure the impulse response from more than one
10 transducer simultaneously.

In order to test the following algorithms, a listening room was set up with a Mk 5a DSP and an omnidirectional microphone at roughly (4:0; 0:0; 0:6), and six repeats of a maximum
15 length sequences (MLS) of $2^{18}-1$ bits was sent at 48kHz to individual transducers by selecting them from the on-screen display. Transducers 0, 9, 33, 57, 66, 90, 114, 123, 133, 159, 193, 219, and 252 were used (13 in all) of the 256 transducer
20 array of the sound projector, forming a roughly evenly spaced grid across the surface of the DSP including transducers at "extreme" position, such as the centre or the edges. The microphone response was recorded to 48kHz WAV-format files for analysis.

25 The time-reversed original MLS was convolved with the response from each transducer in turn and the resulting impulse response normalized by finding the first major peak (corresponding to the direct path) and shifting the time
30 origin so this peak was at $t = 0$, then scaling the data so that the maximum impulse had height 1. The time shift alleviates the need to accurately synchronize the signals.

35 A segment of the impulse response of transducer 0 (in the top-left corner of the array) is shown in FIG. 2. The graph shows the relative strength of the reflected signal relative to the

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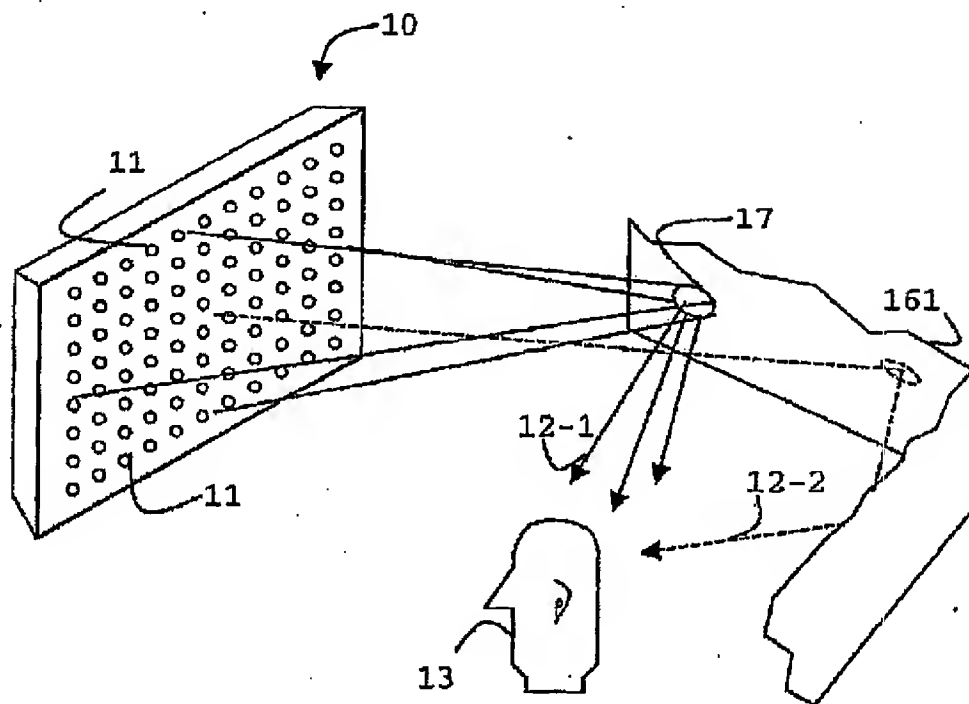


FIG. 1

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A surround-sound system decodes the input audio information and uses the decoded information to distribute the signal among different channels with each channel usually being emitted through one or loudspeaker or combination of two speakers.

In the commonly-owned published international patent applications no. WO-0123104 and WO-02078388 the sound projector generates the surround-sound environment by emitting beams of sound each representing one of the above channels and reflecting such beams from surfaces such as ceiling and walls back to the listener. The listener perceives the sound beam as if emitted from an acoustic mirror image of a source located at or behind the spot where the last refraction took place.

Whereas Sound Projector systems that use the reflections of acoustic beams can be installed by trained installers and closely guided users, there remains a desire to facilitate the set-up procedure for less-trained personnel or the average end user.

The problems associated with the setting up of a sound projector are not related to certain known methods aiming at partial or total wavefield reconstruction. In the latter methods, it is attempted to record a full wavefield at the listener's position. For reproduction a number of loudspeakers are controlled in a manner that closest approximates the desired wavefield at the desired position. Even though these methods are inherently recording reflections from the various reflectors in a room or concert hall, no attempt is made to infer from these recordings control parameters for a sound projector. In essence, the wavefield reconstruction methods are "ignorant" as to the actual room geometry and therefore

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The microphone is modeled by a point in space and is assumed to be omnidirectional. Under the assumption that the reflective surfaces are planar, the system can be thought of as an array of microphone "images" in space, with each image representing a different sound path from the transducer array to the microphone. The speed of sound c is assumed to be known, i.e. constant, throughout, so distances and travel-times are interchangeable.

Given a microphone located at $(x_{mic}, y_{mic}, z_{mic})$ and a transducer located at $(0, y_i, z_i)$, the path distance to the microphone is

$$[1] \quad d_i = (x_{mic}^2 + (y_{mic} - y_i)^2 + (z_{mic} - z_i)^2)^{1/2},$$

which can be rewritten as the equation of a two-sheeted hyperboloid in (d_i, y_i, z_i) space as follows:

$$[2] \quad d_i^2 - (y_{mic} - y_i)^2 - (z_{mic} - z_i)^2 = x_{mic}^2$$

The $^{1/2}$ notation indicates an exponent.

At a listening distance of 3m, the effects of curvature of the hyperboloid are negligible over the available range of y_i and z_i and it can be considered either planar or hyperboloidal.

To measure a impulse response, a single transducer is driven with a known signal, for example five repeats of a maximum length sequence of $2^{18} - 1$ bits. At a sampling rate of 48kHz this sequence lasts 5.46 seconds.

A recording is taken using the omnidirectional microphone within the listening area. The recording is then filtered by convolving it with the time-reversed original sequence and the

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not applicable to the control problem underlying the present invention.

SUMMARY OF THE INVENTION

The present invention proposes the use of one or a combination of two or more of the following methods to facilitate the installation of a sound projector:

A first approach is use a set-up guide in form of an electronic medium such as CDROM or DVD, or a printed manual manual, preferably supported by a video display. The user is asked a series of questions, including details of:

- The mounting position of the sound projector;
- The shape and dimensions of the room; or
- The distance to the listening position from the Sound Projector.

This can either be done through a series of open questions, as in an expert system, or by offering a limited choice of likely answer combinations, together with illustrations to aid clarity.

From this information, a few beam directions for each channel can be pre-selected and stored, for example in form of a list. The sound projector system can then produce short bursts of band-limited noise, cycling repeatedly through each of these directions. For each direction the user is then asked to select a (subjective) best beam direction, for example by activating a button. This step can be repeated iteratively to refine the choice.

Without making use of a microphone, the user might then be asked to select from a menu the type of surface on each wall and on the ceiling. This selection, together with the steering angles as established in the previous step, could be used to

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derive an approximate equalisation curve. Delay and level matching between channels could be performed using a similar iterative method.

5 In variants of the above method where a microphone is used attached to an input socket of the sound projector, a more automated approach can be taken. With an omni-directional microphone positioned at the main listening position, the impulse response can be measured automatically for a large
10 number of beam angles, and a set of local optima, at which there are clear, loud reflections, can be found. This list can be refined by making further automated measurements with the microphone positioned in other parts of the listening area. Thereafter the best beam angles may be assigned to each
15 channel either by asking the user to specify the direction from which each beam appears to come, or by asking questions about the geometry and deducing the beam paths. Asking the user some preliminary questions before taking measurements will allow the search area, and hence time, to be reduced.

20 A faster, automated approach includes the step of measuring the impulse responses between a number of single transducers on the panel and a microphone at the listening position. By decomposing the measured impulse responses into individual
25 reflections and using a fuzzy clustering or other suitable algorithm, it is possible to deduce the position and orientation of the key reflective surfaces in the room, including the ceiling and side walls. The position of the microphone (and hence the listening position) relative to the
30 Sound Projector can also be found accurately and automatically.

35 These and other aspects of inventions will be apparent from the following detailed description of non-limitative examples and drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

5 FIG. 1 is a schematic drawing of a typical set-up of a sound projector system in accordance with the present invention;

FIG. 2 is a graph showing registered responses to a signal emitted by a transducer of the sound projector system;

10 FIG. 3 is a modeled impulse response for a idealized room;

FIG. 4 shows results of cluster analysis performed on registered responses to signals emitted from different transducers of the sound projector system;

15 FIG. 5 summarizes the general steps of a method in accordance with the invention.

DETAILED DESCRIPTION

20 The present invention is best illustrated in connection with a digital sound projector as described in the co-owned applications no. WO-0123104 and WO-02078388.

25 Referring to FIG.1, a digital loudspeaker system or sound projector 10 includes an array of transducers or loudspeakers 11 that is controlled such that audio input signals are emitted as a beam or beams of sound 12-1, 12-2. The beams of sound 12-1, 12-2 can be directed into - within limits - arbitrary directions within the half-space in front of the

30 array. By making use of carefully chosen reflection paths, a listener 13 will perceive a sound beam emitted by the array as if originating from the location of its last reflection or - more precisely- from an image of the array as reflected by the wall, not unlike a mirror image.

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In FIG. 1, two sound beams 12-1 and 12-2 are shown. The first beam 12-1 is directed onto a sidewall 161, which may be part of a room, and reflected in the direction of the listener 13. The listener perceives this beam as originating from an image of the array located at, behind or in front of the reflection spot 17, thus from the right. The second beam 12-2, indicated by dashed lines, undergoes two reflections before reaching the listener 13. However, as the last reflection happens in a rear corner, the listener will perceive the sound as if emitted from a source behind him or her.

Whilst there are many uses to which a sound projector could be put, it is particularly advantageous in replacing conventional surround-sound systems employing several separate loudspeakers placed at different locations around a listener's position. The digital sound projector, by generating beams for each channel of the surround-sound audio signal and steering those beams into the appropriate directions, creates a true surround-sound at the listener position without further loudspeakers or additional wiring.

The components of a digital sound projector system are described in the above referenced published International patent applications no. WO-0123104 and WO-02078388 and, hence, reference is made to those applications.

In the following the steps leading to the automated identification of reflecting surfaces, such as side-wall 161 in FIG.1, in a room with a sound projector.

For the subsequent method it is assumed that the sound projector is centred on the origin and lies in the yz plane where the positive y axis points to the listeners' right and the positive z axis points upwards; the positive x axis points towards the listeners.

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travel path length as calculated from the arrival time.
Several peaks (above -20 dB) are identifiable in the graph,
for example the peaks at 0.4m, 1.2m, 3.0m, 3.7m and 4.4m.

5 Before attempting to associate these peaks with reflectors in
a room, a model of a perfectly reflecting room is illustrated
in FIG. 3.

10 FIG. 3 is a graph of the 'perfect' impulse response of a room
with walls 2.5m either side of the sound projector, a rear
wall 8m in front of it and a ceiling 1.5m above it, as heard
from a point at (4; 0; 0). As the signal is reflected from
reflecting surfaces the microphone measures an reflection image
15 of that surface in accordance with the path or delay values
from equations [1] or [2]. The direct path and reflections
from the ceiling correspond to the first two surface images
311, 312, and the next four intermingled arrivals 313
correspond to the reflections from the sidewalls with and
without the ceiling, respectively. Other later arrivals 314,
20 315 represent reflections from the rear wall or multiple
reflections.

Using the model of FIG. 3, a plausible interpretation of some
of the major peaks of FIG. 2 can be given. Table 1 below lists
25 these interpretations.

TABLE 1.

<u>Distance (m)</u>	<u>Likely source</u>
0	Direct path from transducer to 30 microphone
0.4	Reaction from coffee table
1.2	Reaction from ceiling
3.0, 3.7, 4.4	Reaction from side walls with/without 35 ceiling.

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2.2 Rerun the algorithm.

This method has a number of advantages. Firstly, the algorithm never runs with fewer than $c - 1$ clusters, so the wait for extraneous prototypes to be deleted is minimized. Secondly, the starting point of each run is better than a randomly chosen one, since $c - 1$ of the clusters have been found and the remaining data belongs to the remaining prototype(s).

FIG. 4 shows the results of applying the incremental RFCV algorithm on the second precluster of FIG. 2 using $c = 1$ (FIG. 4A) and $c = 2, \dots, 5$ (FIGs. 4B, ..., 4E, respectively.). In the case of $c=3$ (FIG. 4C) the method converges onto an artifact. As the number of clusters is further increased to $c=4$ and $c=5$ (FIGs. 4D, E) this cluster disappears and the four correctly recognized reflectors are recognized in the data. No further cluster is identified. The clusters are indicated by planes 413 drawn into the data space, which in turn is indicated by black dots 400 representing the impulse response of the microphone to the emitted sequences.

As in an automated set-up procedure the microphone position may be an unknown, any cluster identified according to the steps above, can be used to solve with standard algebraic methods equation [2] for the microphone position x_{mic} , y_{mic} and z_{mic} .

With the microphone position and the distance and orientation of images of the transducer array known enough information is known about the room configuration to direct beams at the listeners from a variety of angles. This is done by reversing the path of the acoustic signal and directing a sound beam at each microphone image.

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However, it is necessary to deduce the direction from which the beam appears to arrive at the listener.

One way of making this deduction is to decide which walls the beam is being reflected in order to arrive at the microphone. If this decision is to be made automatically then it can be for most cases assumed that the walls are all flat and reflective over their whole surfaces. This implicitly means that the secondary reflection of surfaces A and B arrives at the microphone later than the primary reflected signals from surface A and from surface B, which permits the following algorithm:

1. Start by initializing an empty list of walls.
2. Take each microphone image in order of their distances from the DSP and search through all combinations of walls in the list to see if any composition of reflections in those walls could result in the microphone image being in the right place.
3. If such a combination does not exist then this microphone image is formed by a primary reflection in an as-yet-undiscovered wall. This wall is the perpendicular bisector of the line segment from the microphone image to the real microphone. Add the new wall to the list.

A more robust way of comprises the use of multiple microphones or one microphone positioned at two or more different locations during the measurement and determine the perceived beam direction directly.

Using an arrangement with 4 microphones in a tetrahedral arrangement and after having determined the positions of images of each of the microphones individually they can be grouped into images of the original tetrahedron which will

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5 fully specify the perceived beam direction. If the walls are planar then the transformation mapping the real tetrahedron to its image will be an isometry and its inverse equivalently maps the sound projector to its perceived position from the listener's point of view.

10 Using less than four microphones results in an increase of uncertainty in the direction of the arrival. However in some case it is possible to use reasonable constraints, for example, such as that wall are vertical etc, to reduce this uncertainty.

15 The problem of scanning for a microphone image is a 2-dimensional search problem. ~~It can be reduced to two consecutive 1-dimensional search problems using the beam projectors ability to generate various beam patterns. For example it is feasible to vary the beam shape to a tall, narrow shape and scanning horizontally, and then use a standard point-focused beam to scan vertically.~~

20 With a normal point-focused beam the wavefront of the impulse is designed to be spherical, centered on the focal point. If the sphere were replaced with an ellipsoid, stretched in the vertical direction, then the beam will become defocused in the vertical direction and form a tall narrow shape.

30 Alternatively, it is possible to form a tall narrow beam by using two beams focused at two points in space above one another and the same distance away from the sound projector. This is due to the abrupt change of phase between sidelobes and the large size of the main beam in comparison with the sidelobes.

35 The general steps of the above-described method are summarized in FIG. 5.

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CLAIMS

1. A set-up method for a loudspeaker system capable of
5 generating at least one directed beam of audio sound,
comprising the steps of
- emitting a series of signals from the loudspeaker
system into a room including a listener's position; ;
 - registering said series and its reflections at one or
10 more locations within said room;
 - evaluating said registered series to determine a first
set of values for directing parameters for said beam;
and
 - using said directing parameters to direct said beam
15 into the desired direction.
2. The method of claim 1 wherein the series of signals are
emitted from less than the full number of electro-
acoustic transducers in the loudspeaker system.
- 20 3. The method of claim 1 wherein the series of signals are
emitted from single electro-acoustic transducers in the
loudspeaker system.
- 25 4. The method of claim 3 wherein different series of signals
are simultaneously emitted from different electro-
acoustic transducers.
- 30 5. The method of claim 4 wherein the different electro-
acoustic transducers are located at an edge position
and/or the centre of the transducer array.
- 35 6. The method of claim 1 wherein the series of signals are
emitted as spatially-constrained beams of sound to a
range of directions.